EFFECTS OF OFF-ROAD MOTORCYCLE ACTIVITY ON MOJAVE DESERT VEGETATION AND SOIL

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In recent years increased use has been made of the desert for off-road vehicle activity, and the resulting disturbance to the landscape has become increasingly noticeable. This study concerns effects of motorcycle disturbance on vegetation and soils of a representative portion of the Mojave Desert. Motorcycle disturbance is here interpreted as the effects not only of motorcycle race trails across the desert but also of off-road parking of vehicles. In fact, the greatest disturbance in a concentrated area apparently takes place in "pit areas", where vehicles are parked at the scene of a race. Intensity of disturbance and size of pit area depend on number and density of vehicles parked, duration of stay, and number of times they return during the year and from year to year. For example, near the study area there is a large pit area (at least 10 ha) from which races have been started for more than ten years. This area is nearly devoid of vegetation, and the soil is hard-packed. Smaller pit areas in the vicinity usually cover one to two hectares, with varying degrees of disturbance to the vegetation and soils, and have been used for racing events only a few times.

Two kinds of motorcycle race take place in this part of the desert—the enduro and the scramble. Both kinds of races follow preset courses or trails that may be as long as 300 km.

The effect of motorcycle disturbance on the vegetation and soil is due to running over plants and disruption and compaction of surface soil. Thus, if disturbed areas were compared to equivalent undisturbed areas, reduction in total numbers of plants, reduction in number of plant species, increase in the number of dead shrubs, and increase in the bulk density or degree of compaction of the soil in disturbed areas would be expected.

Disturbance both to pit areas and to trails was studied. One representative pit area and one trail were used for vegetation and soil analysis, and sample plots and/or transects were established. Adjacent to these disturbed areas, equivalent sites, which were not disturbed by motorcycle activity, were similarly studied.

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Site Description and Methods

Pit Area—Site A is located 12–16 km NE of California City, Kern County, California, in low, rolling hills. This pit area had been used several times prior to 1973 but had not been disturbed for the past year. The degree of disturbance was only moderate compared to that of other pit areas in this part of the Mojave Desert. The vegetation at this location and at the trail site described later belongs to the Creosote Bush Scrub community as described by Munz (1959). The soil at Site A and also at the trail site was formed of unconsolidated alluvium derived from the adjacent uplands, which are largely granitic and metamorphosed sedimentary rock. At Site A, the soil is a sandy loam, pH 8.0, lacking $CaCO_3$.

A 1 ha plot that covered most of the area of intense disturbance was subjectively established on the Site A pit area. In order to compare the pit area disturbance with equivalent, relatively undisturbed vegetation, a control 1 ha plot was subjectively established several hundred meters away from the pit area. An effort was made to select an equivalent site with respect to potential vegetation, topography, and surface soil.

Within both plots at Site A, two parallel 100 m transects were established, each transect lying 20 m from a side of the hectare plot and oriented perpendicularly to the direction of the slope. Herbaceous plants were sampled along each transect using a 0.25 m^2 quadrat placed every 4 m along the transects. Numbers of individuals of each species rooted within the quadrat were recorded in each quadrat. Shrubs were sampled by recording the presence of all shrubs rooted within a 3 m wide strip along one side of each transect. For each individual shrub, position along the transect and a visual estimate of the diameter of the canopy were recorded. For statistical analysis it was necessary to divide shrub data taken from each plot into ten equal and consecutive sections, each representing 60 m^2.

Six randomly selected soil samples were taken from the disturbed plot and five randomly chosen samples were taken from the undisturbed plot. Two methods were used to obtain soil samples. The core method was used for the undisturbed plot, and the clod method was used for the disturbed plot, where the coring instrument could not be driven into the hard, compacted soil. These two methods are described in detail by G. R. Blake (1965).

The average pore space for each sampled area was determined, using the equation:

$$\text{pore space } (\%) = 100 - (D_b/D_p \times 100)$$

where D_b is the bulk density of the soil, and D_p the average particle density, usually about 2.65 g/cc (Hausenbuiller, 1972).

Trail—Site B is a portion of a 240 km trail made by a motorcycle enduro race on 7–8 April 1973. Sampling was done on 14–15 April 1973 on a short length of this trail, about 11 km west of Randsburg, Kern County, California. The landscape is a gently sloping plain intersected with shallow washes. The soil is a fine sandy loam, pH 7.0, lacking $CaCO_3$.

A 100 m transect was established along the middle of the trail. A 3 m long rod was placed perpendicularly to the transect every 8 m, and herbaceous plants were sampled using 0.25 m^2 quadrat placed on one side of the rod within each of the three meters of the rod. The number of individual plants of each herbaceous plant species rooted within the quadrat was recorded. Shrubs were sampled by recording the presence of all shrubs rooted within a 3 m wide strip along the same side of the transect. For each individual shrub, position along the transect, distance from the transect, and diameter of the canopy were recorded.

In order to demonstrate degrees of disturbance related to distance from the center of the 3 m wide trail, the data were compiled as three parallel subtransects: subtransect 1 (center of trail); subtransect 2 (edge of trail); subtransect 3 (off the trail).

The same sampling technique used on the trail was used for a 100 m transect parallel to the trail and about 50 m away. This transect was considered to be in relatively undisturbed vegetation. Data from three subtransects within this control transect were combined.

Thus thirty-nine 0.25 m^2 quadrats for each 100 m transect were sampled for herbaceous plants, and 300 m^2 of continuous area was sampled for shrubs. For statistical analysis, it was necessary to divide the shrub data taken from each transect into ten equal and consecutive sections, each representing 30 m^2.

Five soil samples were taken at 30 m intervals along the disturbed transect in the middle of the trail and also along the undisturbed transect. The core method described earlier was used to obtain the soil samples.

Results

In general, the data are presented in this section so as to compare aspects of vegetation and soils in the disturbed areas to those at the matched undisturbed areas. Pertinent differences in both the vegetation and soils data were tested for their statistical significances, using the one-tailed t-test for two independent samples (Siegel, 1956).

Vegetation Data. Numbers and frequency of each species of herbaceous plant are shown for each plot or transect in Tables 1 and 2. Numbers and average canopy cover per individual for each species of shrub in the plot or transect are shown in Tables 3 and 4. The numbers of dead shrubs are included.

TABLE 1. HERBACEOUS VEGETATION AT PIT AREA (SITE A). N = number of individuals encountered. F = frequency of encounter in total of fifty 0.25 m^2 quadrats.

	Disturbed plot		Undisturbed plot	
	N	F	N	F
Astragalus didymocarpus	13	0.10	33	0.28
Amsinckia intermedia	18	0.10	13	0.14
Baeria debilis	19	0.12	695	0.78
Chaenactis fremontii	24	0.28	35	0.36
Chorizanthe brevicornu	2	0.04	2	0.04
Coreopsis calliopsidea	1	0.02	....	......
Cryptantha micrantha	1	0.02	1	0.02
Cryptantha nevadensis	....	......	1	0.02
Eriogonum gracillimum	3	0.06	....	......
Eriogonum pusillum	1	0.02	....	......
Eriophyllum pringlei	....	......	19	0.08
Erodium cicutarium	601	0.88	1043	1.00
Eschscholzia minutiflora	16	0.12	11	0.16
Filago depressa	....	......	1	0.02
Gilia minor	9	0.10	54	0.40
Lepidium flavum	....	......	55	0.22
Lotus strigosus	....	......	21	0.22
Malacothrix coulteri	....	......	8	0.16
Malacothrix glabrata	....	......	2	0.02
Mentzelia veatchiana	9	0.10	14	0.14
Nama demissum	10	0.14	....	......
Pectocarya platycarpa	1	0.02	....	......
Phacelia fremontii	3	0.04	12	0.16
Phacelia tanacetifolia	1	0.02	2	0.04
Plagiobothrys arizonicus	10	0.12	....	......
Schismus barbatus	191	0.72	38	0.14
Syntrichopappus fremontii	1	0.02	....	......
Thelypodium integrifolium	30	0.46	1	0.02
Totals	980		3615	

According to the hypotheses stated in the introduction, motorcycle disturbance was expected to cause a decrease in the number of live plants, an increase in the number of dead shrubs, a decrease in the average canopy per individual shrub, and a decrease in diversity in an area where disturbance had occurred. In nearly all cases, the data show increases or decreases where they are expected. In a few instances the expected trends are reversed: number and cover per shrub of *Acamptopappus sphaerocephalus* in both sites; number of dead shrubs in Site A; canopy cover per shrub of *Ambrosia dumosa* in Site B; and number of *Schismus barbatus* in Site A. In regard to plant diversity, an obvious decrease in the number of species is seen in the herbaceous vegetation at Site B. Fourteen species were counted in the undisturbed transect, but only seven species were counted in the disturbed transect.

TABLE 2. HERBACEOUS VEGETATION AT TRAIL (SITE B). N = number of individuals encountered. F = frequency of encounter in total of thirty-nine 0.25 m^2 quadrats.

	Disturbed plot					Undisturbed plot	
	N (subtransects)				F	N	F
	1	2	3	Σ			
Amsinckia intermedia						1	0.03
Anisocoma acaulis	1	0	2	3	0.08	1	0.03
Cryptantha micrantha	0	1	2	3	0.08	2	0.03
Cryptantha pterocarya	0	2	0	2	0.05	2	0.03
Erodium cicutarium	0	0	5	5	0.08	12	0.12
Gilia latifolia						3	0.03
Lupinus odoratus						1	0.03
Malacothrix glabrata						3	0.08
Malvastrum exile	0	1	6	7	0.05	4	0.03
Mentzelia veatchiana	3	10	6	19	0.26	45	0.54
Nama demissum						1	0.03
Oenothera dentata						3	0.05
Plagiobothrys arizonicus						1	0.03
Schismus barbatus	4	48	48	100	0.61	315	0.95
Totals	8	62	69	139		394	

Statistical tests comparing differences between disturbed and undisturbed areas at each site gave confidence points equal to or less than 0.2 to the following values: total numbers of herbaceous plants at both sites (0.001); total numbers of *Ambrosia dumosa* shrubs at Sites A and B (0.2 and 0.05, respectively); average canopy cover per *Ambrosia dumosa* shrub at Sites A and B (0.01 and 0.2, respectively); and average canopy cover per *Larrea divaricata* shrub at Site A (0.1).

Soil Data. In Site A, the disturbed plot soil had an average bulk density of 1.67, with an average pore space of 37.0 percent, and the undisturbed plot had an average bulk density of 1.46 with an average pore space of 45.0 percent. The confidence point of the difference between these average bulk densities is 0.005. In Site B, the disturbed transect (trail center) had an average bulk density of 1.66, with an average pore space of 37.3 percent. The undisturbed transect had an average bulk density of 1.59, with an average pore space of 40.0 percent. The confidence point of the difference between these average bulk densities is 0.1.

It is possible that the clod method, used for the disturbed plot of Site A, gave higher values for the bulk density than the core method would have given, since the clod method did not take interclod spaces into account. However, it was noted at the time the samples were taken that few interclod spaces or cracks existed in the disturbed plot soil at Site A.

TABLE 3. SHRUB VEGETATION AT PIT AREA (SITE A). D = disturbed plot. U = undisturbed plot. Number = numbers of living shrubs encountered. Cover = average canopy cover per shrub (m^2).

Taxon	Number		Cover	
	D	U	D	U
Acamptopappus sphaerocephalus	22	2	0.06	0.04
Ambrosia dumosa	25	52	0.06	0.14
Eurotia lanata	1	....	0.02	......
Larrea divaricata	26	28	0.95	1.33
Lycium andersonii	....	1	......	0.20
Machaeranthera tortifolia	1	....	0.02	......
Tetradymia stenolepis	....	6	......	0.48
Total living shrubs	75	89		
(Dead shrubs	74	52)		

DISCUSSION AND CONCLUSIONS

Vegetation. Statistical treatment of the data points out only one consistently significant difference between disturbed vegetation and undisturbed vegetation—namely, a loss of the herbaceous plant cover in both sites. Even more indicative of this effect are the totals of herbaceous plants on the three subtransects of the disturbed transect on Site B, which show a drastic decline in the number of herbaceous plants in subtransect 1, the middle of the motorcycle race trail (See Table 2). The relative permanence of the loss of the herbaceous vegetation is shown in the data from Site A, which was not disturbed during the 1973 growing season. At this site herbaceous plants had not returned to their normal densities.

Two introduced species, *Erodium cicutarium* and *Schismus barbatus,* are the most common herbaceous species found on the study sites. At Site A, *Schismus barbatus,* an annual grass, is the only herbaceous species for which densities were higher in the disturbed areas than in the undisturbed. At Site B, disturbance occurred only one week prior to sampling, and many *Schismus barbatus* plants present along the trail were destroyed at that time. Evidently, density of *Schismus barbatus* increased following disturbance at Site A; it is reasonable to expect that the numbers of this species will also greatly increase along the trail at Site B in the next growing season.

Based on statistical analyses, definitive conclusions cannot be made on the effects of motorcycle activity on the vegetation other than the significant loss of herbaceous vegetation. Nevertheless, with few exceptions, the data show an overall trend toward fewer plants and less cover per individual shrub in the disturbed areas than in undisturbed areas.

TABLE 4. SHRUB VEGETATION AT TRAIL (SITE B). D = disturbed plot. U = undisturbed plot. Number = numbers of individuals of living shrubs encountered. Cover = average canopy cover per shrub (m^2).

Taxon	Number					Cover	
	D (subtransects)				U	D	U
	1	2	3	Σ			
Acamptopappus sphaerocephalus	8	20	16	44	29	0.12	0.12
Ambrosia dumosa	12	45	24	81	135	0.22	0.19
Eurotia lanata	....	....	....	....	3	......	0.17
Larrea divaricata	1	7	7	15	13	0.51	0.77
Total living shrubs	21	72	47	140	180		
(Dead shrubs	14	27	24	65	51)		

It is believed that the ambivalent results of the statistical tests reflect subtle site differences between disturbed and undisturbed plots and transects, not the lack of effect from motorcycle disturbance. The effect of site differences on the data might have been lessened by more extensive sampling. Evidence for possible non-equivalence of disturbed and undisturbed plots is: (1) a greater number of shrubs in disturbed plots than in undisturbed plots (*Acamptopappus,* Sites A and B; *Larrea,* Site B); and (2) greater cover per individual plant in disturbed plots than in undisturbed plots (*Acamptopappus,* Sites A and B). These differences in the vegetation could be due to variation of such factors in the soil as depth, composition, or moisture. If such variations caused an increase in the density and cover of shrubs in the disturbed plots or transects, the effects of motorcycle disturbance would be masked.

Significance of the data for dead shrubs is not known because of the difficulty of reliably determining whether a plant was destroyed by a motorcycle or whether it died naturally and had disintegrated. The situation in Site A where more dead shrubs were found in the undisturbed plot than in the disturbed plot may be explained as follows: The Site A pit area has been used a number of times in the past several years, but not during the present year. Many dead shrubs on the disturbed plot may have disintegrated and blown away or have been used as firewood by cyclist groups, resulting in fewer dead plants as compared to the undisturbed plot.

At Site B, the paucity of shrubs in disturbed subtransect 1 (trail center) would seem to reflect a significant destruction of shrubs by motorcycles. While this is undoubtedly true to some extent (reflected by the significantly smaller total number of shrubs in the disturbed transect compared to the undisturbed transect), caution is used in making this interpretation. When numbers of shrubs in subtransects 2 and 3 of the disturbed transect are compared, the number of shrubs in subtransect 3 was found to be less (Table 4). This was not expected, since subtransect 2 was closer to the center of the trail. Further, canopy cover per individual *Ambrosia dumosa* shrub in subtransect 3 exceeded that in subtransect 2. The probability of either of these differences occurring by chance is 0.1. These observations indicate the existence of some pattern in the vegetation bordering the trail. In reality, it is reasonable to assume that the first cyclists to run the race did not ride in a straight line oblivious to the shrubs, but rather, guided their vehicles between the shrubs. Most shrubs that were avoided by the cyclists were recorded in subtransect 2, resulting in the high number of shrubs in that subtransect. Whether the cyclists made their own pattern through the vegetation or whether they were inadvertantly following some natural pattern in the shrub vegetation is not known. In either case, if the trail were widened by increased use, the large number of shrubs bordering the trail would be damaged or destroyed.

Soils. Pore space of a soil is the volume that is not taken up by solid particles; it normally contains air and water. This space consists of macropores that allow the ready movement of air and water, and micropores in which air movement is impeded and water moves largely by slow capillary movement. Desert soils of this area are relatively coarse, with a relatively high proportion of larger particles such as sand and gravel. Sandy soils normally show a range of 35 to 50 percent pore space, while heavy surface soils with a larger clay content show a range of 40 to 60 percent pore space (Buckman and Brady, 1960).

With greater compaction from off-road vehicles, soil particles are pressed closer together and the bulk density is increased. The small increase in bulk density seems insignificant when the disturbed areas are compared to the undisturbed; there is probably a proportionately larger decrease in the percentage of macropores in the disturbed areas.

The increase in bulk density of disturbed soils as shown in this study, with the resulting decrease in macropore space, probably decreases the amount of water that the soil can hold and the rate at which water can flow through the soil (Yang and DeJong, 1971). It also reduces the permeability of the soil so that runoff is greater (Kubota and Williams, 1967). Consequently, there is a reduction of the water stored in the soil and available for plant growth.

Since the storms in the Mojave Desert are generally short and intense, much of the rainfall cannot be absorbed by the soil and runs off the surface (Troxell and Hoffman, 1954). Desert rainfall is also very low and sporadic in the Mojave Desert: 50–130 mm per year, with occasional completely dry years and others with as much as 230 mm (K. Berry, personal communication). Because of this climate factor, and because the sandy desert soils are never high in available water, lack of soil water is a limiting factor, and any decrease in the amount of water entering the soil and available for plants would certainly be detrimental to the vegetation in a disturbed area.

In addition to possible decrease of available water in the soil due to compaction, there may be a more direct effect on plants. Kubota and Williams (1967) found that compaction of a light sandy loam decreased germination, root growth, and size of shoots of barley and globe beet. Phillips and Kirkham (1962) showed that compacted soils impeded root growth. The somewhat unimpressive differences in bulk density of the sampled soils belie the actual hardness of the compacted soil in the disturbed areas compared to that of undisturbed desert soil. While a sharpened metal stake could usually be shoved by hand into the undisturbed soil, it required a sledge in most locations of both the pit area and the trail. It seems likely that this hardness of the soil of disturbed areas would inhibit the growth of roots of desert plants that are adapted to a looser soil condition.

There is evidence that the effects of either lack of soil water or root growth impedence, or both, may be influencing vegetation at Site A. Although the Site A pit area was not disturbed during the 1973 growing season, density of annual plants was very low compared to adjacent undisturbed areas. Since the supply of light-weight seeds from annual plants growing in surrounding areas is probably more than sufficient to reseed the pit area, it appears that the compacted soil in the Site A pit area is no longer an adequate seedbed for seed germination and seedling growth.

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A NEW SPECIES OF HACKELIA (BORAGINACEAE) FROM OREGON

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During the preparation of a revision of some of the northwestern American taxa of *Hackelia*, specimens representing an undescribed species were encountered. The taxon is known only from the Three Forks region of the Owyhee River, southeastern Malheur County, Oregon. It was apparently first collected by Milton L. Dean, who did a floristic study of the area in 1957 and 1958 (Dean, 1960).

Hackelia ophiobia R. L. Carr, sp. nov.

Planta perennis viridis, radice crassiuscula gradatim angustata, caudicibus fasciculatis ab petiolis persistentibus vestitis. Caules graciles sparsim strigosi. Folia rosulae longiuscule petiolata, ovata vel oblonga, 5–15 cm cum petiolo longa, 15–35 mm lata, apice obtusa mucronulata, basi nunc truncata nunc cordata, aequabiliter hirsutula. Folia caulium elliptica vix reducta, inferiora in petiolum attenuata, superiora sessilia, omnia hirsutula. Inflorescentia laxa ramosa, bracteis inferioribus usque 2 cm longis, superioribus gradatim parvioribus. Pedicelli recurvi 12–17 mm longi. Lobi calycis strigillosi lanceolati acuti 3–4 mm longi. Corolla limbo rotato 6–8 mm lato caeruleo, tubo albido vel flavo calyce aequilongo. Fornices corollae truncato-rotundati breviter papillati. Nuculae ovoideae, 2.3–3.3 mm longae 1.2–2.1 mm latae, dorsaliter parum glochidiatae, muriculatae, vix alatae, aculeis marginalibus principalibus 1.0–1.5 mm longis, ad basim distinctis, cum aculeis brevioribus interspersis. Cicatrix nuculae ad centrum, ovata. Figures 1 and 2.